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The Numerical Forecast Model BKF(G): Characteristics and Experiences

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REVIEW AND APPROVAL STATEMENT

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This document has been reviewed and is approved for publication.

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19. Abstract: The BKFG model is used by the German Military Geophysical Office (GMGO) and is available to the European Forecast Unit (EFU) for retransmission over the AFDIGS circuit. This tech note explains the model itself and the output available to AFDIGS users.

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FOREWORD

This technical note provides the forecaster the necessary information to understand the physics used in these products. Understanding the strengths and weaknesses of this tool should make more accurate forecasts. The people of the European Forecast Unit (EFU) at Det 13, 2WW, went to great effort to have this valuable tool available to the Air Weather Service forecaster.

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INTRODUCTION

The replacement of the GEOVOR computer at the German Military Geophysical Office (GMGO) near the end of 1986 made possible the use of better atmospheric models due to increased computing capacity.

Specifically, the synoptic scale models 7LPE-CM (hemispheric, gridpoint spacing 381 km) and 7LPE-LFM (North Atlantic/European window, gridpoint spacing 127 km) were replaced by a more powerful model. These models, used by the GMGO since 1982, were limited by the model physics and numerical methods available in 1980. Advancements in these fields gave modelers the power to upgrade these models.

Due to the existing cooperation between the DWD and the GMGO in the area of model development, an agreement was reached to implement the DWD hemispheric model BKF at the GMGO in a version specifically adapted to the GEOVOR computer system. This new version is called the BKFG (G for GMGO).

After extensive program adaptation and testing, the BKFG was available for routine use on GEOVOR and replaced the 7LPE as the standard GMGO model on 3 May 1988.

The BKFG is a 9-layer primitive equation model with an effective horizontal resolution of 180 km. The computer code corresponds to the DWD version of the BKF as of March 1986. The quality of the forecast is highly dependent on the initialization fields. Deviations from DWD-products can therefore result due to different analysis procedures, the use of climatology instead of analysis in the surface model, and a different data supply due to a different 'cutoff' time. The analysis procedures are continuously being improved, and the climatology fields are replaced by analyses in the working process.

In spite of these limitations, a verification test of the BKFG forecasts performed by the GMGO during a 6-month period revealed significant improvement in the important products over the 7LPE-LFM model. Regardless of the somewhat poorer horizontal resolution, better vertical resolution, more detailed model physics, and the avoidance of window model boundary value problems account for the improved products. For a detailed description of the BKFG model, the reader is referred to the GMGO Int .nal Report Nr. 79137.

NUMERICAL FORECAST MODELS

<table>
<tr><td>SCALE</td><td colspan="2">Synoptic Scale (Macro Scale)</td><td colspan="2">Local Scale (Meso Scale)</td></tr>
<tr><td>GRID</td><td>Coarse Mesh</td><td>Fine Mesh</td><td>High Resolution</td><td>Local</td></tr>
<tr><td>FORECAST AREA</td><td>Northern Hemisphere</td><td>Europe, North Atlantic</td><td>Central Europe</td><td>100 x 100 km^2</td></tr>
<tr><td>MESHWIDTH</td><td colspan="2">180 km</td><td>63.5 km</td><td>~2 km</td></tr>
<tr><td rowspan="2">ROUTINE MODELS</td><td colspan="2" rowspan="2">BKFG

Primitive equations, including
- moisture, precipitation
- orography
- friction
- sensible heat
- latent heat
- radiation</td><td rowspan="2">BLM

Primitive eq
hydrostatic
(model used
for regional
forecasting)</td><td>FITNAH

Primitive eq
non-hydrostat
(model used
for local
phenomena
forecasting)</td></tr>
<tr><td>STATISTICAL TECHNIQUES</td></tr>
<tr><td>BACKUP MODELS</td><td>BKL3/5

Quasi-geostro-
phic equations
including
- orography
- friction
- sensible heat
- latent heat</td><td>BKL3/5 (FM)

Window model
with time-
dependent
boundary
conditions</td><td></td><td></td></tr>
</table>

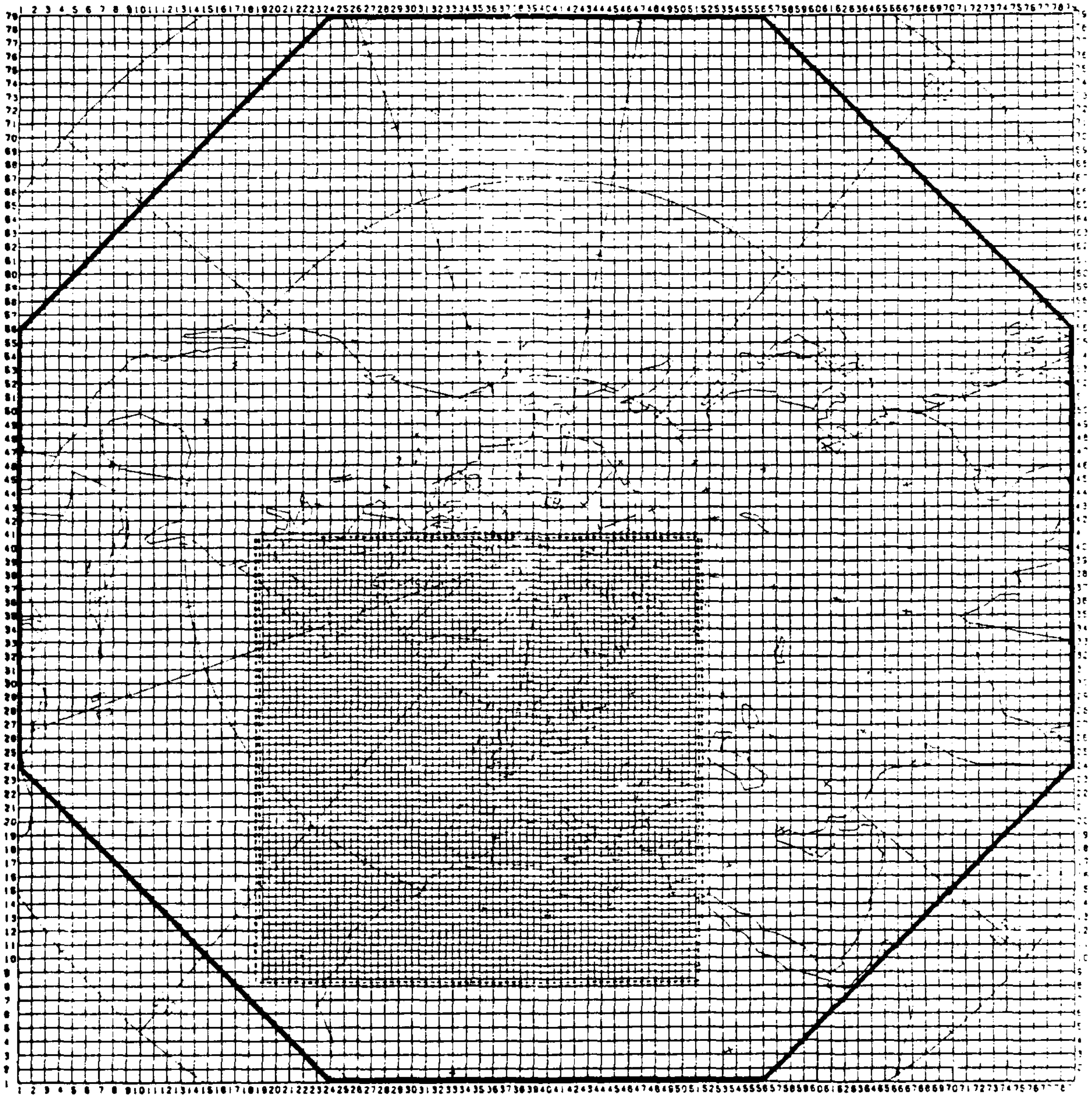
BKFG GRID

HEMISPHERIC GRID

BKFG COARSE MESH ANALYSIS & FORECAST
NUMBER OF GRIDPOINTS: 79 X 79
GRIDPOINT SPACING: 254 km

WINDOW GRID

BKFG FINE MESH FORECAST
NUMBER OF GRIDPOINTS: 65 X 65
GRIDPOINT SPACING: 127 km



BKFG BASIC EQUATIONS

a. PROGNOSTIC EQUATIONS:

1. Horizontal equations of motion:

$$\frac{\delta v_1}{\delta t} + m^2\left(v_1\frac{\delta v_1}{\delta x} + v_2\frac{\delta v_1}{\delta y}\right) + \omega\frac{\delta v_1}{\delta p} + \frac{1}{2}\left(v_1^2 + v_2^2\right)\frac{\delta m^2}{\delta x} - f v_2 = -\frac{\delta \Phi}{\delta x} + D(v_1)$$

$$\frac{\delta v_2}{\delta t} + m^2\left(v_1\frac{\delta v_2}{\delta x} + v_2\frac{\delta v_2}{\delta y}\right) + \omega\frac{\delta v_2}{\delta p} + \frac{1}{2}\left(v_1^2 + v_2^2\right)\frac{\delta m^2}{\delta y} + f v_1 = -\frac{\delta \Phi}{\delta y} + D(v_2)$$

2. First Law of Thermodynamics:

$$\frac{\delta \theta}{\delta t} + m^2\left(v_1\frac{\delta \theta}{\delta x} + v_2\frac{\delta \theta}{\delta y}\right) + \omega\frac{\delta \theta}{\delta p} = H + D(\theta)$$

3. Moisture Conservation Equation:

$$\frac{\delta q}{\delta t} + m^2\left(v_1\frac{\delta q}{\delta x} + v_2\frac{\delta q}{\delta y}\right) + \omega\frac{\delta q}{\delta p} = R + D(q)$$

4. Tendency Equation:

$$\frac{\delta \Phi_o}{\delta t} = \omega_o \cdot \frac{RT_o}{P_o}$$

b. DIAGNOSTIC EQUATIONS:

1. Hydrostatic equation:

$$\frac{\delta \Phi}{\delta p} = -\frac{R}{P_o}\left(\frac{P_o}{P}\right)^{1-\kappa}\theta \cdot (1 + 0.604q)$$

2. Continuity equation:

$$\frac{\delta \omega}{\delta p} = -m^2\left(\frac{\delta v_1}{\delta x} + \frac{\delta v_2}{\delta y}\right)$$

c. TERMS EXPLAINED:

V_1, V_2 Covariant horizontal velocity components
ω Vertical velocity in the X,Y,P coordinate system
θ Potential temperature
q Specific humidity
H Sources and sinks for heat
R Sources and sinks for humidity
D (Ψ) Turbulent flux of variable Ψ due to internal friction and boundary layer phenomena
m Scaling factor (stereographic plane)

BKFG MODEL PHYSICS

SURFACE	Composition: land, ocean, ice, and variable snow cover. Two layers with prognostic variables temperature and soil water content.
OROGRAPHY	Vertical walls (mountains) inhibit flow. Air is lifted over the barrier.
BOUNDARY LAYER	Combination of Prandtl and Ekman layers allowing calculation of boundary layer fluxes using surface roughness and Richardson number as the determining parameters.
CONVECTION	Parameterization of deep convection by the parcel method. Vertical velocity is calculated from the lifting force and determines the intensity of the convective exchange. The following are considered: - slow sinking of the surrounding air - entrainment
CLOUDS	Parameterization through linear dependence on relative humidity
PRECIPITATION	Consideration of stratiform and convective precipitation. Condensate is not stored in clouds and immediately falls through lower model layers (where it can evaporate), reaching the surface as rain or snow depending on the temperature.
RADIATION	In the troposphere (950-300 mb): - heating by shortwave radiation depends on -- sun angle -- water vapor concentration - cooling by long-wave radiation (1.8 + 0.017 * T °C/day) -- reduced below clouds -- increased above inversions Upper surface layer: - shortwave heating depending on sun angle, cloud cover, albedo - long-wave cooling depends on cloud cover (counter-radiation)

BKFG NUMERICAL METHODS

INDEPENDENT VARIABLES	x, y, p, t
PROGNOSTIC VARIABLES	v_1, v_2, θ, q, ϕ_{1000}, TS, TU, BS, BU
DIAGNOSTIC VARIABLES	ω, ϕ

GRID STRUCTURE

a. Horizontal	Octagonal, 79 x 79 grid points with 254km grid spacing (at 60 N) using stereographic projection. Muller grid ('staggered'): all variables except defined at the grid point; 2 types of grid points (red/black) diagonally shifted by 1/2 grid point with distribution of variables depending on time step; → effective grid spacing 180 km.
b. Vertical	x, y, p coordinate system ($0 \leq p \leq 1000$mb) 9 layers for v_1, v_2, θ, q 2 surface layers

TIME INTEGRATION — Explicit, centered (leapfrog scheme), Δt = 1/14 hour. Averaging over 2 starting periods (to damp out high-frequency initial waves) and over double time steps (to avoid diverging solutions)

SPATIAL DIFFERENCING

a. Horizontal	Centered
b. Vertical	Centered, vertical advection represented as in flux form.

HORIZONTAL DIFFUSION — 4th order linear smoothing operator

BOUNDARY CONDITIONS

a. Lateral	Variables along octagonal border constant in time, smoothing in vicinity of border.
b. Top (p = 0)	$\omega = 0$
c. Bottom (p = 1000)	w = 0 (kinematic boundary condition)

BKFG INITIALIZATION FIELDS

PARAMETER	UNITS	BELOW SFC 50 cm	BELOW SFC 5 cm	SFC	1000	950	850	700	550	500	400	300	200	100	50	
1. ANALYSES																
PRESSURE	mb			X												
GEOPOTENTIAL	gpm					X	X	X	X			X	X	X	X	
TEMPERATURE	C				X	X	X	X	X			X	X	X	X	
RELATIVE HUMIDITY	%					X	X	X	X							
WATER TEMPERATURE	C			X												
SNOW DEPTH	cm			X												
SOIL WATER CONTENT	mm	X	X													
2. PROG + 12 HR																
GEOPOTENTIAL	gpm					X	X	X	X			X	X	X	X	X
TEMPERATURE	C	X	X													
WIND: U-COMPONENT	m/s					X	X	X	X			X	X	X	X	X
WIND: V-COMPONENT	m/s					X	X	X	X			X	X	X	X	X
3. SFC PARAMETERS																
ALBEDO	%/10			X												
SURFACE FRICTION	-			X												
OROGRAPHY	m			X												

BKFG CALCULATED PRODUCTS

PARAMETER	UNITS	BELOW SFC 50 cm	BELOW SFC 5 cm	SFC	1000	950	850	700	550	500	400	300	250	200	150	100	50
PRESSURE	mb			X													
GEOPOTENTIAL	gpm				X	X	X	X	X	X	X	X	X	X	X	X	X
TEMPERATURE	C	X	X		X	X	X	X	X	X	X	X	X	X	X	X	
RELATIVE HUMIDITY	%				X	X	X	X	X	X	X	X					
WIND: U-COMPONENT	m/s				X	X	X	X	X	X	X	X	X	X	X	X	X
WIND: V-COMPONENT	m/s				X	X	X	X	X	X	X	X	X	X	X	X	X
OMEGA	mb/h							8 INTERMEDIATE LEVELS									
PRECIPITATION	mm			X													
SNOW DEPTH	cm			X													
SURFACE WATER CONTENT	mm	X	X														
CONVECTION	-							6 LAYERS									
CLOUDS/FOG	-							3 LAYERS									
WIND DIRECTION	DEGREES				X		X	X		X	X	X	X	X	X	X	
WIND SPEED	KNOTS				X		X	X		X	X	X	X	X	X	X	
OMEGA (QUASI-GEOSTROPHIC)	mb/h				X		X	X		X	X	X	X	X	X	X	
RELATIVE VORTICITY	10^-[illegible]/s				X		X	X		X	X	X	X	X	X	X	
THICKNESS	gpm							4 LAYERS									
VORTICITY ADVECTION	10^-[illegible]/s²				X												
THICKNESS ADVECTION	gpm/h							1 LAYER									

ROUTINE PRODUCTION SCHEDULE

	ANALYSIS	FORECAST PERIOD
00Z		
02Z	00Z	+0H ... +36H
04Z	00Z	+0H ... +72H
06Z		
08Z		
10Z		
12Z	00Z	+0H ... +12H
14Z	12Z	+0H ... +36H
16Z		
	12Z	+36H ... +48H
18Z		
20Z		
	12Z	+0H...+72H...+168H
22Z		
24Z		
t		

BKFG WEAKNESSES

1. General weaknesses

- The BKFG is limited by the octagonal grid requiring significant data smoothing south of 30°N.
- Grid point models cause truncation errors due to the data only being input and calculated at a specific point.

2. Model physics

- Homogeneous surface composition doesn't take into account the difference between urban vs wooded or rural areas. Temperature and humidity errors can occur.
- Missing analysis of ice coverage can cause problems for the radiation scheme when calculating sensible heat flux and albedo.
- Uncertainties in boundary layer parameterization due to missing Ekman spiral. Turning of the winds isn't considered.
- Missing cloud water phase in precipitation scheme can cause over forecast of precipitation since the model precipitates out any water as soon as it reaches the condensation level.
- Highly simplified radiation scheme for surface and free atmosphere (950-300 mb) is used due to the amount of time it would take to run a more complex scheme. Products would be delayed a few hours.

3. Numerical Methods

- Explicit time integration requires small time-step making computation time longer.
- Leapfrog scheme yields phase errors with short waves causing them to be too slow.
- Poor vertical resolution in the boundary layer and in the vicinity of the tropopause.
- Artificial lateral boundary conditions require significant smoothing (no conservation of mass).
- Lower boundary condition represented in the x,y,p coordinate system not the most efficient but it reduces interpolation error.

4. Initialization

- No differentiation during time averaging between fast synoptic waves and very long 'noise' waves with the same frequency.
- Octagonal model area does not permit 'non-linear normal mode' initialization.

VERIFICATION COMPARISON
BKFG/7LPE

The verification procedure tests forecast versus observed changes with respect to the average values of the parameters in question. It is valid for the Central European/East Atlantic window and gives reliability averages for the testing period of 1 Nov 87 - 29 Feb 88. Statistics show that the BKFG did significantly better than the LFM through the 72-hour point. Notice that both models tend to get worse near the 72-hour panel. Care should be taken when using these extended forecasts.

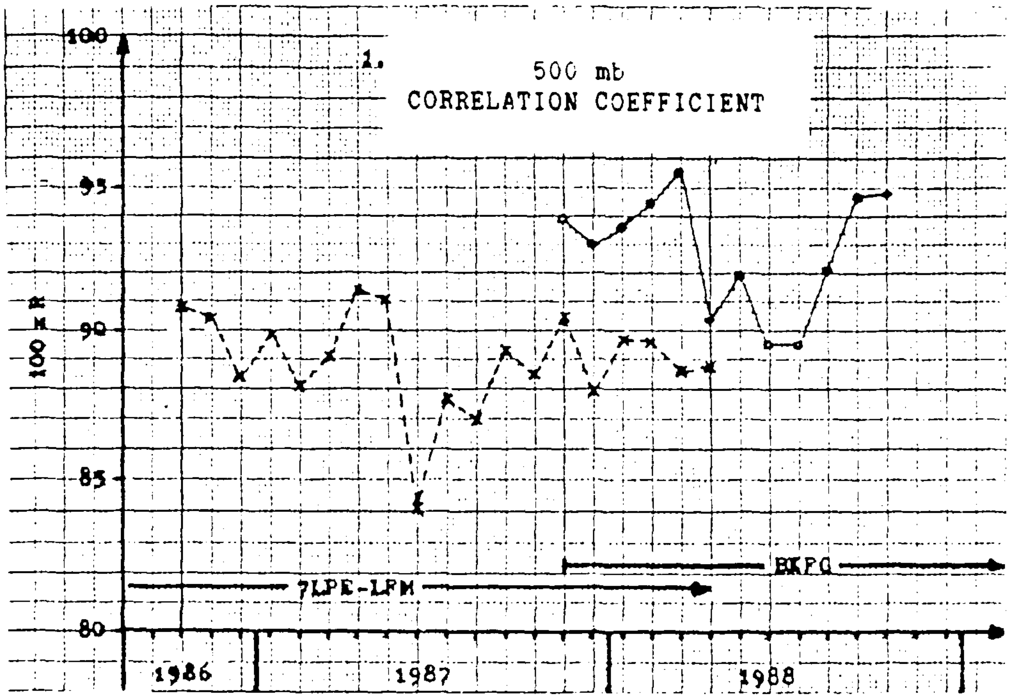
I. Correlation Coefficient R (Phase error)

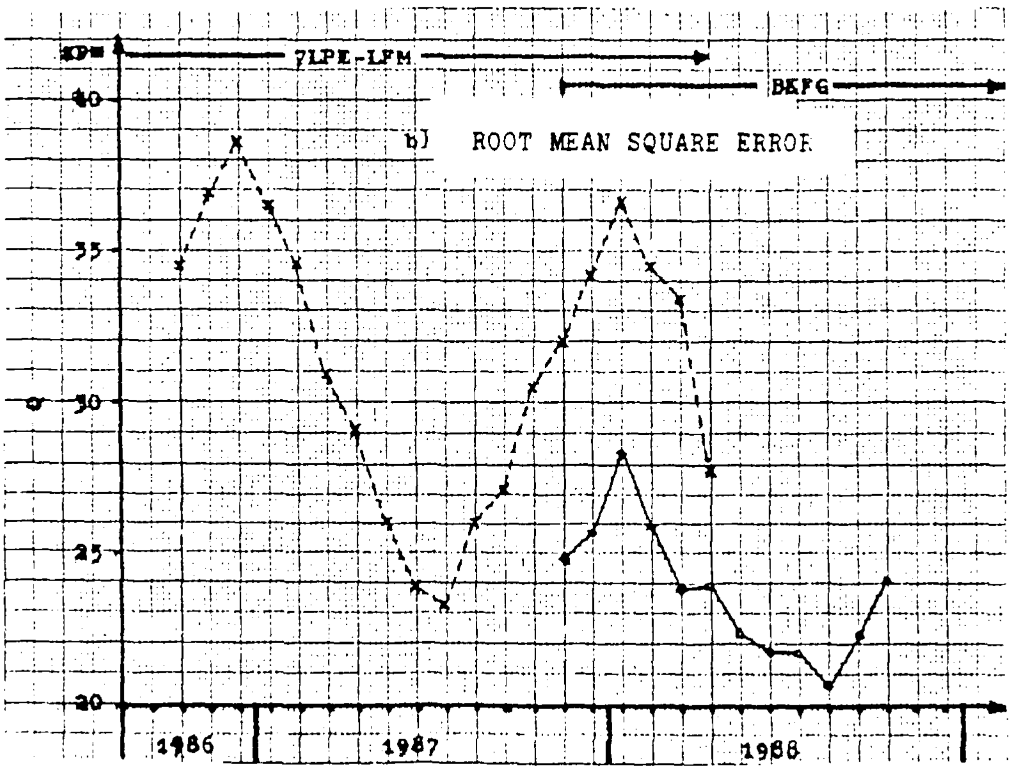
	BKFG					*7LPE-LFM*			*COARSE MESH*	
R	*+12H*	*+24H*	*+36H*	*+48H*	*+72H*	*+12H*	*+24H*	*+36H*	*+48H*	*+72H*
H(1000)	0.92	0.92	0.89	0.86	0.78	0.84	0.87	0.85	0.81	0.73
H(500)	0.93	0.94	0.92	0.90	0.81	0.86	0.89	0.88	0.86	0.77
T(700)	0.85	0.90	0.89	0.87	0.78	0.81	0.87	0.86	0.84	0.74

II. Root Mean Square (RMS) Error Q (Amplitude Error)

	BKFG					*7LPE-LFM*			*COARSE MESH*	
Q	*+12H*	*+24H*	*+36H*	*+48H*	*+72H*	*+12H*	*+24H*	*+36H*	*+48H*	*+72H*
H(1000) gpdm	1.40	2.24	3.09	3.86	5.38	2.06	2.80	3.66	4.50	6.02
H(500) gpdm	1.67	2.62	3.60	4.55	6.64	2.54	3.43	4.43	5.08	7.29
T(700) K	1.27	1.61	1.95	2.30	3.05	1.47	1.73	2.12	2.43	3.22

BKF/BKFG VERIFICATION





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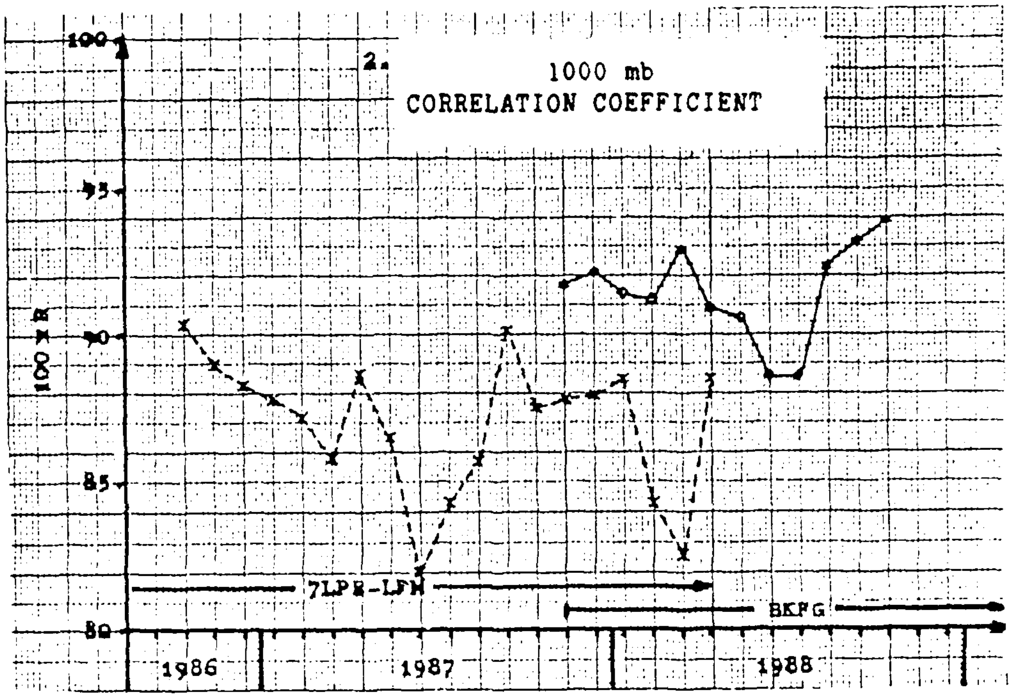
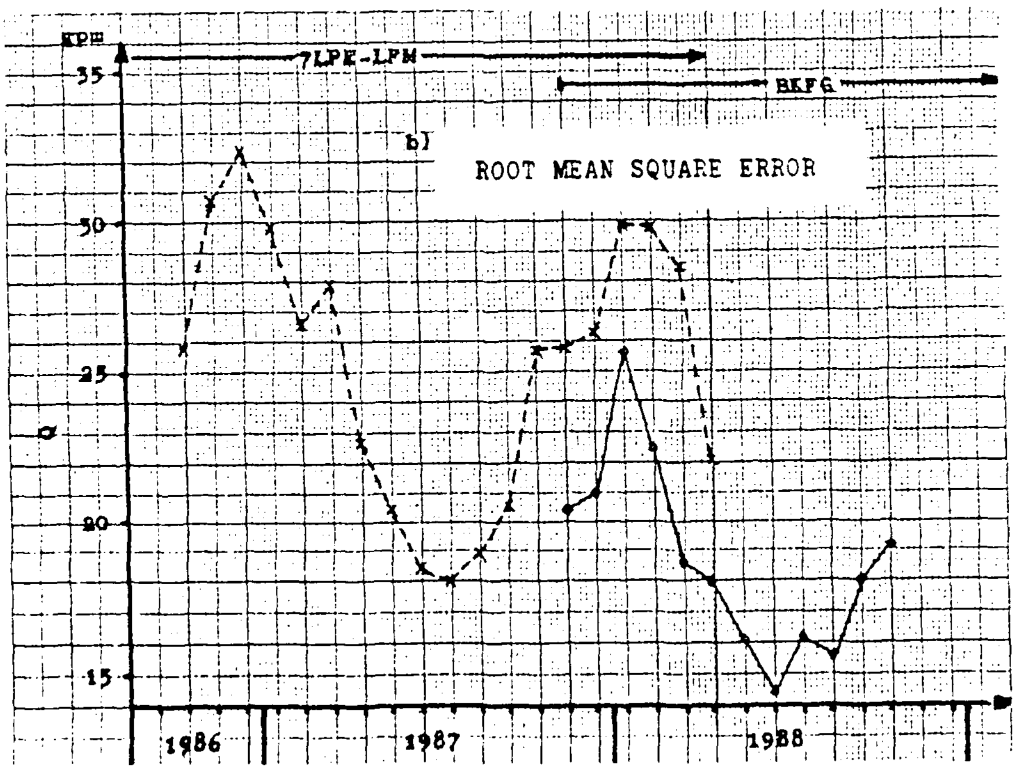
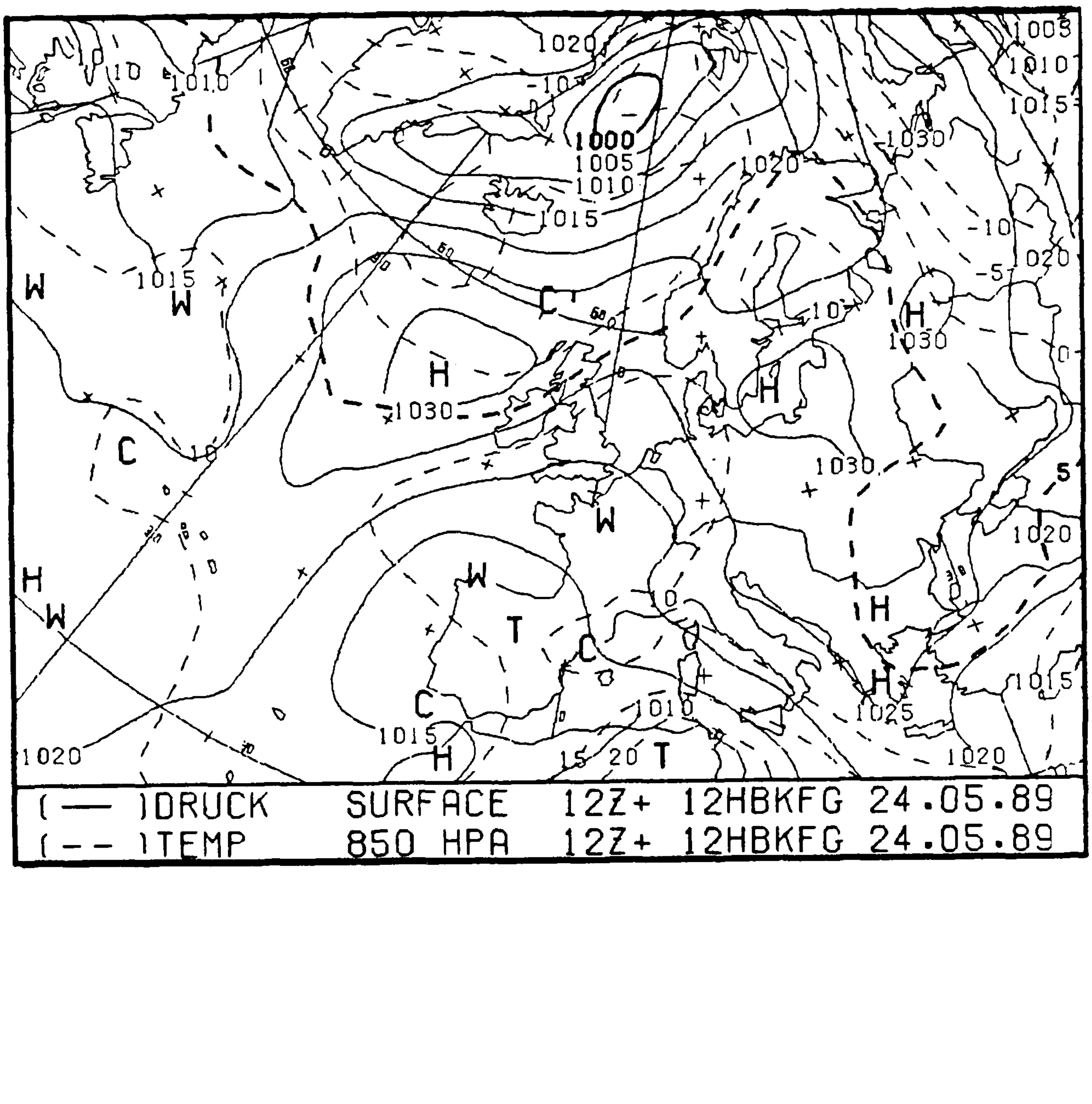


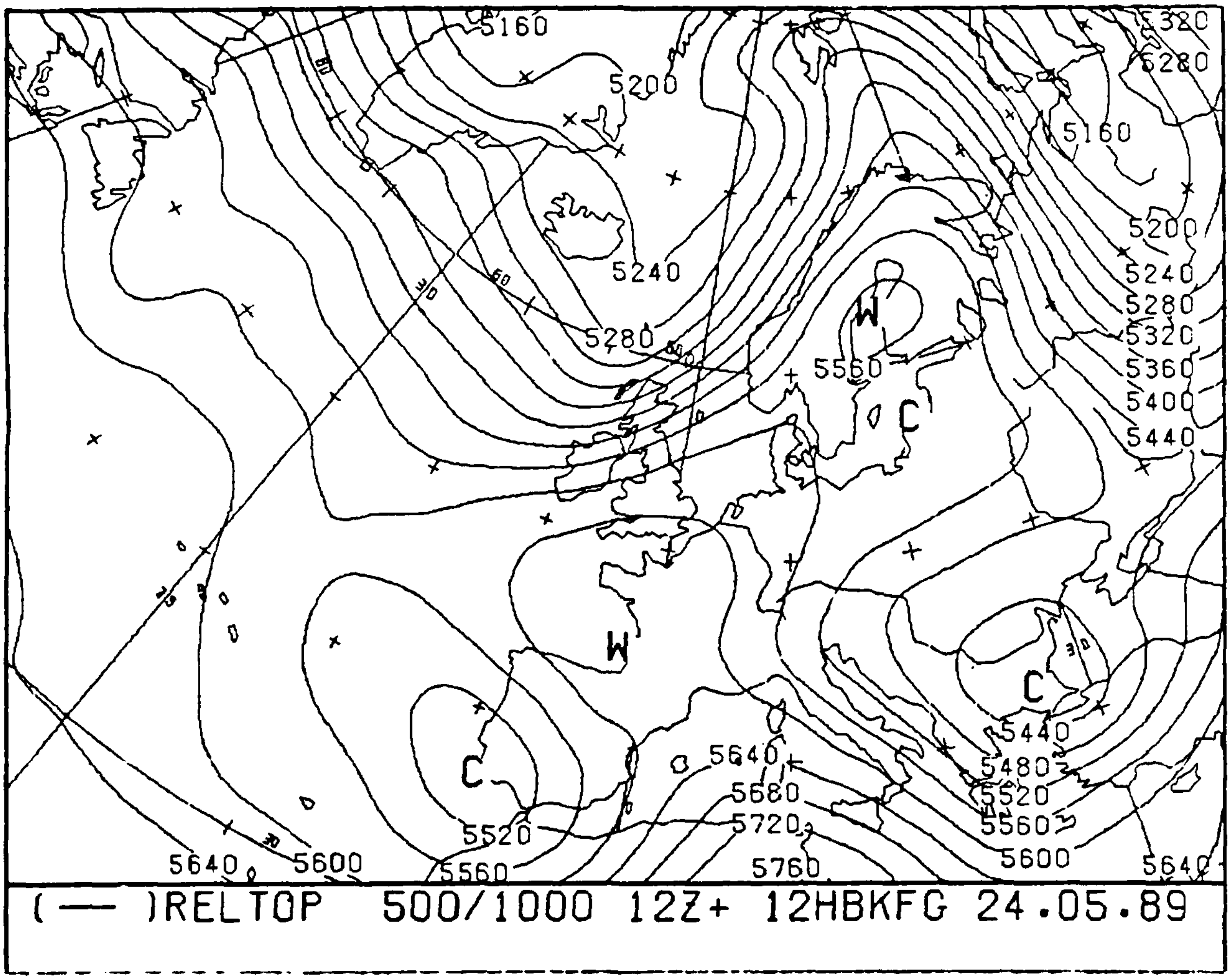


TRANSMITTED PRODUCTS WITH DESCRIPTIONS

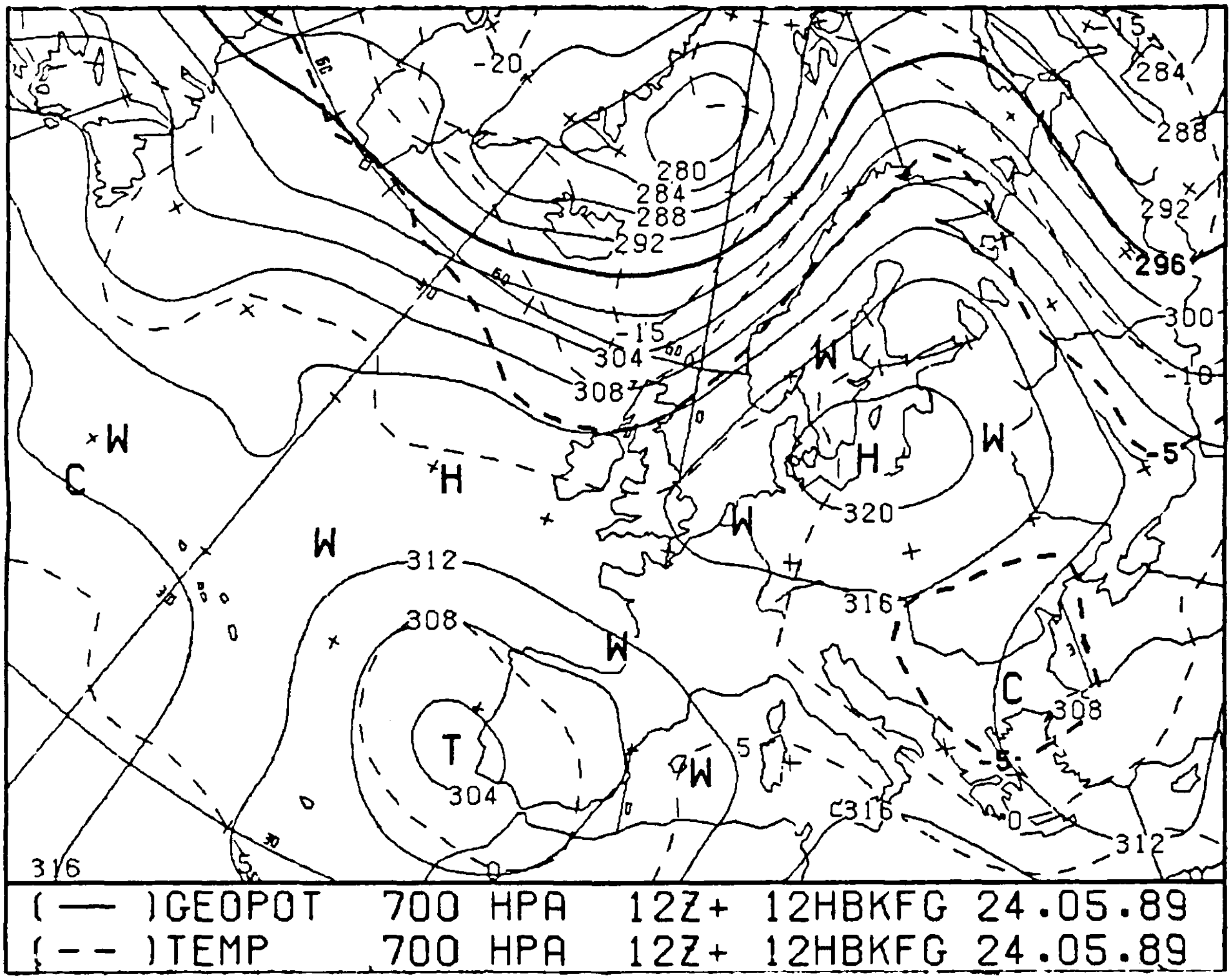
Following are the BKFG fields routinely transmitted over EURDIGS to all 2WW units. Descriptions of the parameters found on each field follow the panel.



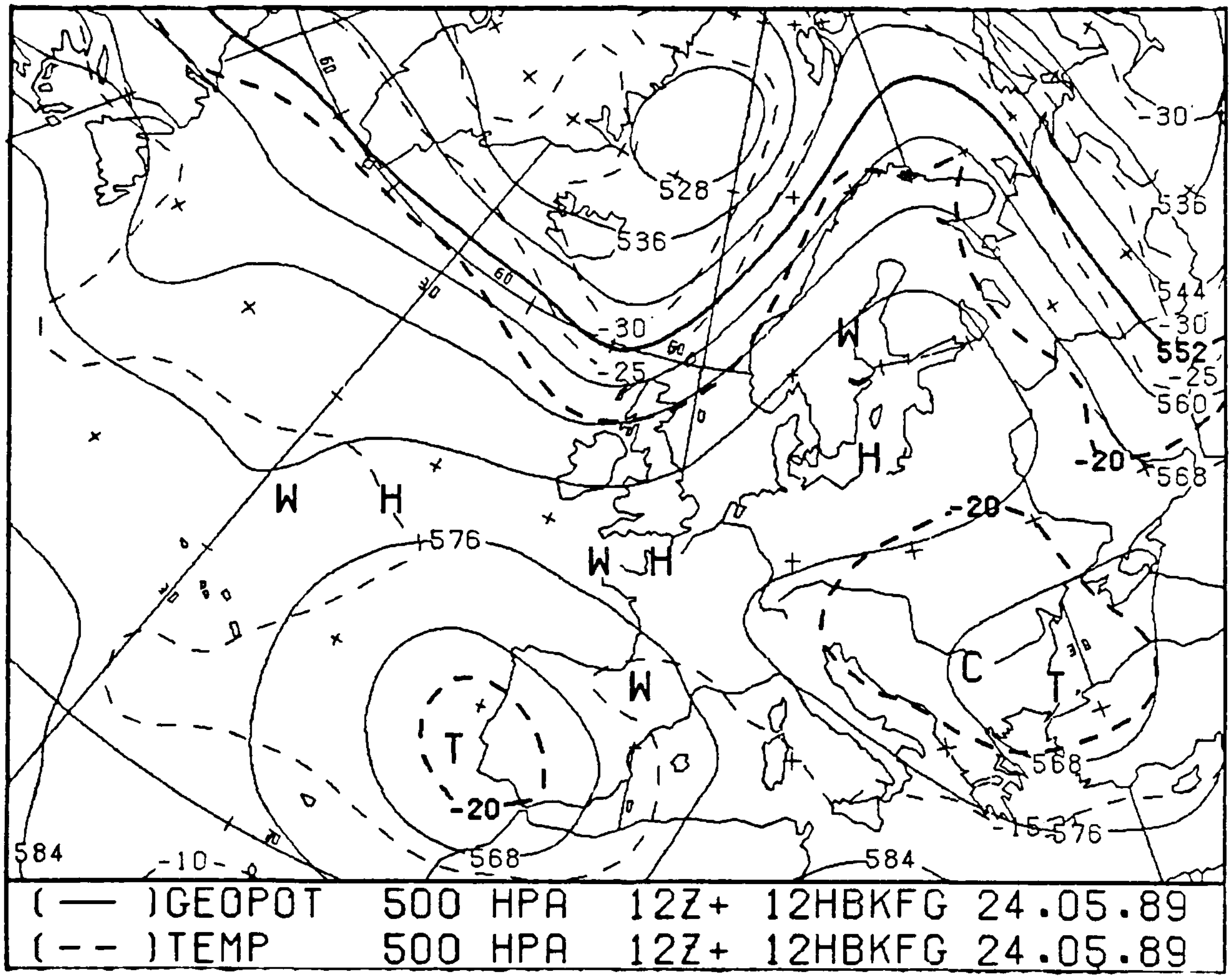
Surface pressure in millibars and 850 mb temperatures in C. H represents high pressure while T represents low pressure. C & W depict areas of cold and warm air.



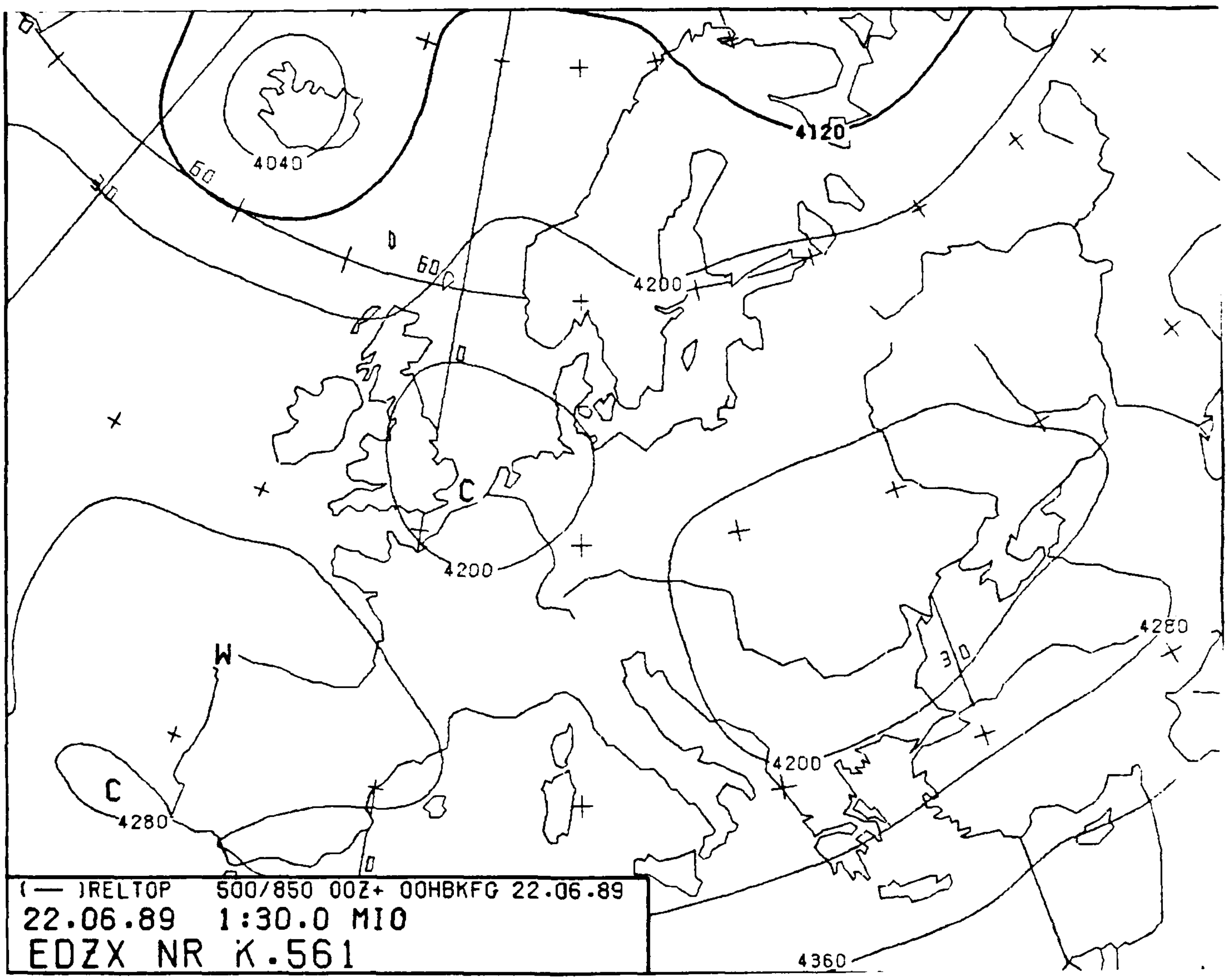
500/1000 mb thickness. Heights in geopotential meters.



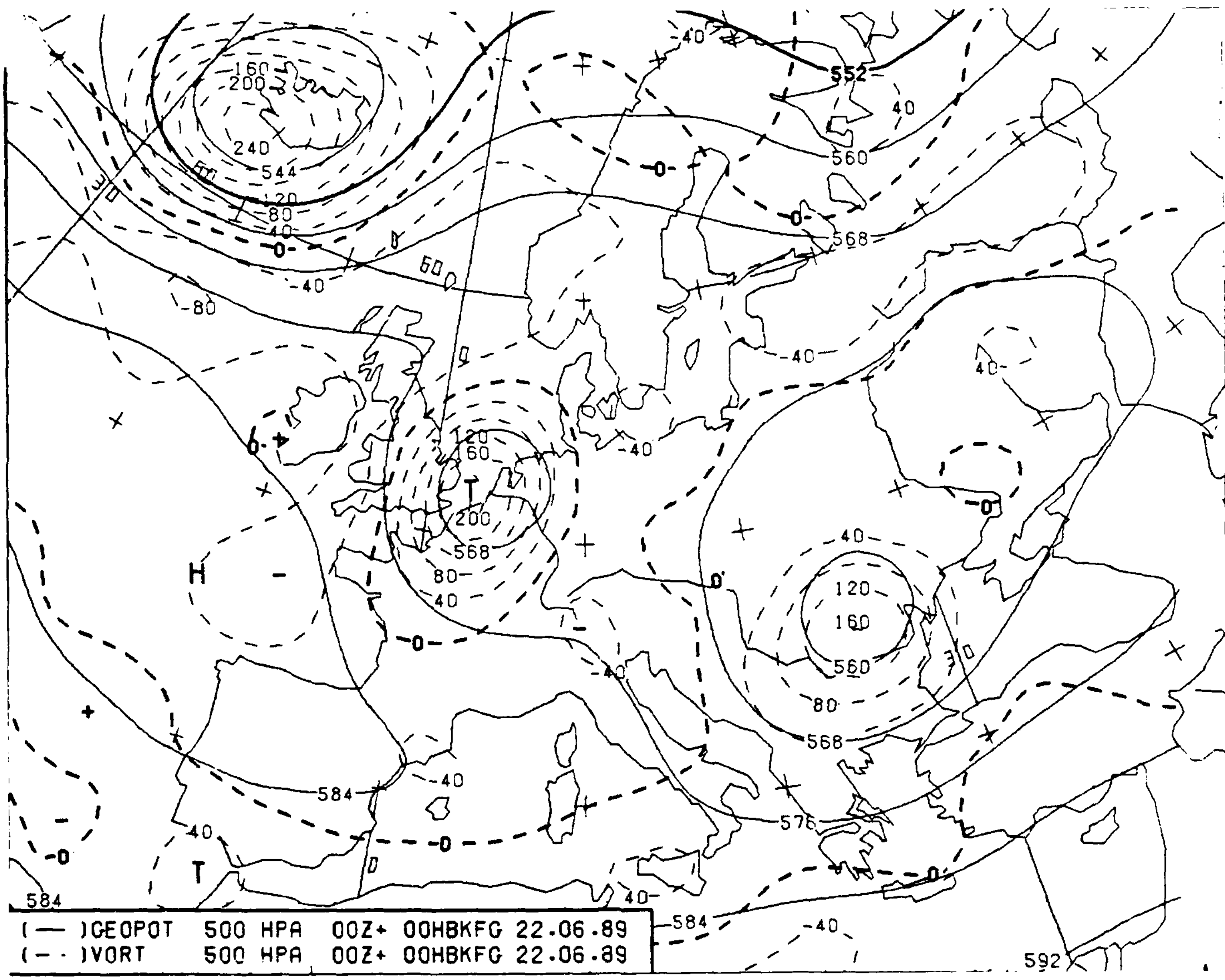
700 mb geopotential heights in decameters and 700 mb temperature in °C.



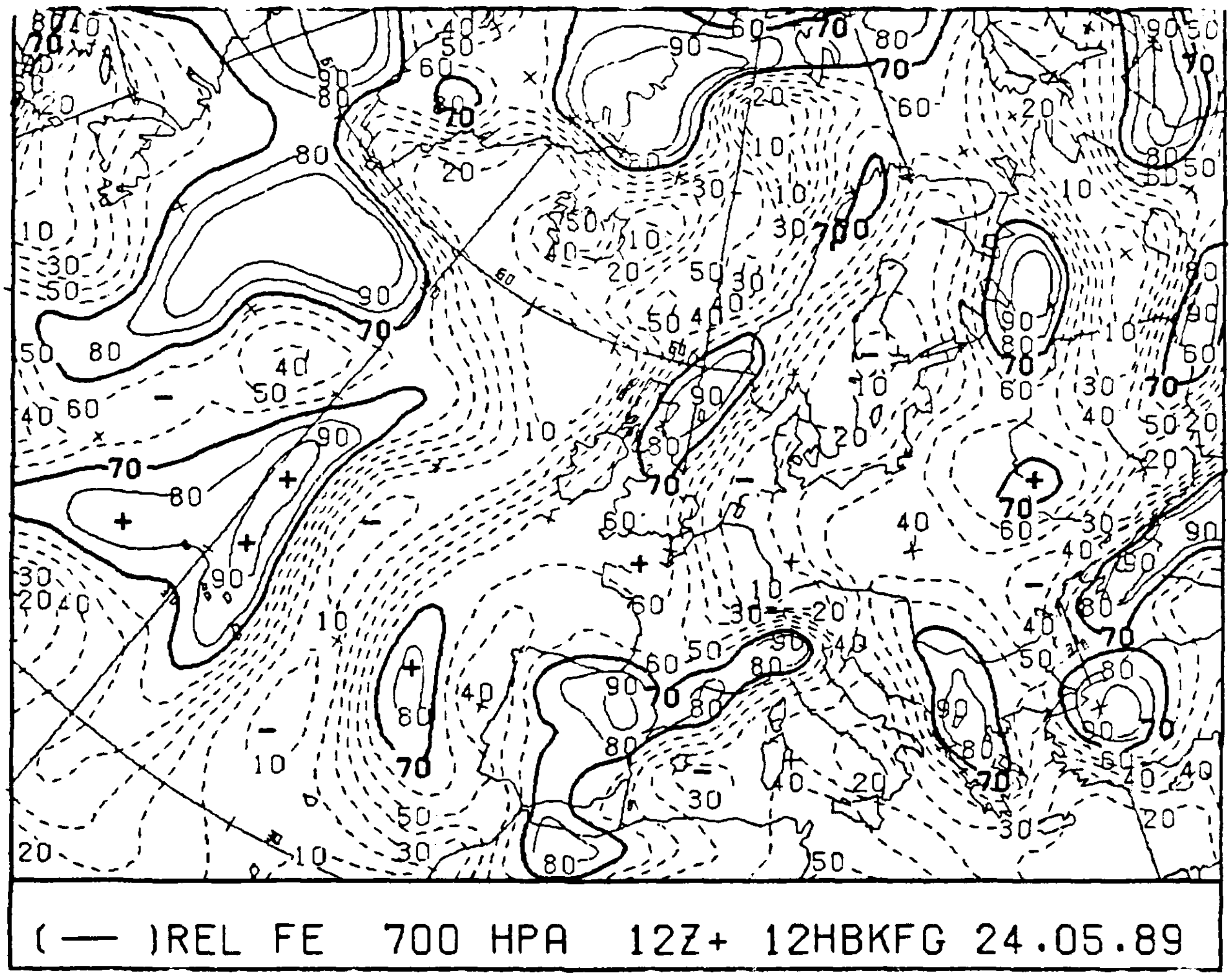
500 mb geopotential heights in decameters and 500 mb temperature in °C.



500 to 850 mb thickness mb in meters.



500 mb geopotential, heights in decameters and 500 mb vorticity.



700 mb relative humidity in %. +/- refer to areas of maximum and minimum relative humidity.

TECHNICAL NOTE DISTRIBUTION

AWSTL, SCOTT AFB IL 62225-5008	5
AWS/DOZ, SCOTT AFB IL 62225-5008	1
AFGWC/DO, OFFUTT AFB, NE 68113-5000	1
3350 TECHTG/TTGU-W, STOP 62, CHANUTE AFB IL 61868-5000	1
1 WW/DN, HICKAM AFB HI 96853-5000	1
2 WW/	
OL-B/OIC, 2 WW, APO NY 09305	1
DET 6, 2 WW/CC, APO NY 09128	1
OL-A, DET 6, 2 WW, APO NY 09050-5000	1
DET 13, 2 WW/CC, APO NY 09122	1
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7 WS/DON, APO NY 09403-5000	26
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